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Coupling of energy and agricultural policies on promoting the production of biomass energy from energy crops and grasses in Taiwan

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ABSTRACT

This paper examined promotion programs and implementing regulations that provide a framework for the application of energy and agricultural policies for the local energy crops cultivation by the reactivation of fallow land (about 100,000 ha) and their utilizations in the bioenergy production in Taiwan. The contents were thus addressed on current energy supply and biomass energy production, estimation of carbon dioxide (CO_2) emissions from energy use (consumption) using the Reference Approach of the Intergovernmental Panel on Climate Change (IPCC) method, national energy goal in biomass energy supply in the near future, and government policies and measures for encouraging bioenergy production and consumption. For the promotion of biofuels, the incentive programs were initiated in the period of 2006–2011. The potential benefits of the program include the upgrade of industrial investment in the bioenergy plants, the reactivation of fallow land (about 100,000 ha), the mitigation of CO_2 emissions, and so on. Concerning the utilization of napier grass (a potential energy grass) as biomass energy (electricity generation) for co-firing, its impacts on ambient air quality and non-CO_2 greenhouse gases (i.e., CH_4 and N_2O) emissions were also discussed in the paper.

Contents

1. Introduction

With the rapid industrialization in the past decades, Taiwan, which is located in the southeastern rim of Asia and is a densely populated island country (i.e., population density: 640 people/km^2; total area: 36,000 km^2) with only limited natural resources, is now on the way to developed countries. Although this country is rich in renewable energy resources such as solar energy [1], it is well-known that the nation has nearly no fossil energy resources such as crude oil and natural gas. It, undoubtedly, is a high energy-importing country. The dependence on imported energy (including coal, petroleum, natural gas liquids, and nuclear power) is

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gradually increasing from 95.8% in 1990 to 99.3% in 2007. The energy supply totaled 147.24 million kL of oil equivalent (KLOE) in 2007, in contrast to 58.57 million KLOE in 1990 [2]. On the other hand, the environmental issues such as global warming related to carbon dioxide (CO_2) emissions from energy consumption are consecutively arousing the concern of the public in recent years. In response to the Kyoto Protocol adopted in Dec. 1997, Taiwan first convened the National Energy Conference in May 1998. One of the most important conclusions was to increase the share of biomass energy in Taiwan's total energy supply in the near future. For this reason, energy strategies and policies for promoting biomass energy must be active in providing some environmental, agricultural, and financial/economic incentives [3].

Based on the statistical data in 2004 [4], it indicates that Taiwan ranks No. 1 in carbon dioxide emissions per gross domestic product (GDP) in the world. It should be also noted that the CO_2 emissions (from energy consumption) per capita in Taiwan increased by over 130% since 1990, which was approximately in parallel with the energy consumption per capita. In response to the Kyoto Protocol effective in Feb. 2005, Taiwan further convened the Second National Energy Conferences in June 2005. According to one of the significant highlights of the Conference, the target share in renewable energy in terms of CO_2 emission reduction is 4.7 million metric tons in 2025, including bioethanol promotion goals of achieving at least 100×10^4 kL in 2010, 200×10^4 kL in 2015, and 300×10^4 kL in 2020, biodiesel promotion goals of achieving 100×10^3 kL in 2010, and 150×10^3 kL in 2020, biomass-to-cogeneration promotion goals of achieving 74×10^4 kW in 2010, and 103×10^4 kW in 2020, and energy crops plantation goal of promoting 100,000 ha in 2010 [5].

The biomass energy from biomass resources such as energy crops and grasses has received much attention in recent years. In order to maintain a harmonious balance among the agricultural production, energy security and environmental protection, the central competent authority (i.e., Council of Agriculture, COA) has developed a sustainable agricultural policy and taken a set of promotion measures to encourage the plantation of local energy crops for the production of biodiesel (from soybean, sunflower, and rapeseed) and bioethanol (from sweet potato and sugarcane) in the years of 2006–2011. It is expected that the program will make many fallow farmlands (about 250,000 ha) into green energy production field progressively. Other ministry-level departments (i.e., Environmental Protection Administration, Ministry of Economic Affairs, and Ministry of Finance) have recently made some innovative regulations and policies to provide financial subsidy, technology assistance and economic incentives to the promotion of biofuels (i.e., biodiesel and alcoholic fuels) for the purpose of creating a balance among economic development, energy supply, and environmental protection.

In my previous papers [6,7], the description centered on promotion regulations/policies especially concerning the waste edible oils-to-biodiesel and molasses (one of sugar manufacturing by-products)–to-bioethanol in the measures of environmental protection and economic/financial incentives. On the other hand, many species of grasses have been considered as renewable sources because they are the most abundant flowering plants in the tropical and sub-tropical regions [8]. Napier grass (*Pennisetum purpureum*), which is also known as elephant grass, is the most famous C_4 perennial grasses as a forage crop and non-forage energy crop due to its advantages: fast growth, disease resistance, adaptability, minimal management, and easy propagation [9]. Therefore, the objectives of this paper were to present an updated review and innovative information on promotion of biofuels and energy crops/grasses in Taiwan. These approaches will play a relevant role in integrated policies that will be expected to offer cost-effective strategies and to provide a potential demonstration for other "developing" countries. The main subjects of this paper were thus listed in the following key elements:

- Overview of current energy supply, energy consumption and biomass energy production.
- Estimation of CO_2 emissions relating to the energy use.
- National energy goal in bioethanol and biodiesel supply.
- Government policies and measures for encouraging biofuels production and consumption.
- Environmental considerations for utilizing napier grass as biomass energy.

2. Overview of current energy supply, energy consumption and biomass energy production

2.1. Current status of energy supply and energy consumption

From the data in Table 1 [2], it can be seen that national reliance on imported energy gradually rose from 95.8% in 1990 to 99.3% in 2007. As a result, Taiwan could be probably ranked as one of the countries in the world which are most dependent on energy import. Due to the nation's energy policy on diversifying imported energy sources, it has also been observed that the reliance on imported petroleum oil slightly decreased from 55.4%% in 1990 to 51.3% in 2005, in contrast to the reliance on imported coal increased from 23.3% in 1990 to 31.9% in 2005 [7]. Some notable points were further addressed as follows:

(1) The amount of total energy supply in Taiwan increased from 58.6 million kL of oil equivalent in 1990 to 147.2 million KLOE in 2007, which is equivalent to an annual average growth rate of 5.7%. In contrast, the growth rate is consistently parallel to the average economic growth (i.e., 5.0%) at the same period based on the data on GDP [10].
(2) In response to the national energy policies on stabilizing energy supply and promoting clean energy, the structure of energy supply by energy form in Taiwan has changed as follows: Shares of imported coal and liquefied natural gas (LNG) continuously increased from 23.3 and 1.6% in 1990, respectively, to 31.9% and 7.6% in 2005, respectively. In 2007, coal and LNG contributed 32.1% and 8.1%, respectively, which showed an increase of 4.9% and 6.8%, respectively, over the previous year (2006).
(3) The amount of indigenous energy supply in Taiwan significantly decreased from 2444.2×10^3 KLOE in 1990 to 998.5×10^3 KLOE in 2007. Coal was ever the most indigenous energy in Taiwan. However, it was no longer produced by the local mines and has been all imported since 2001. Other indigenous energy such as petroleum, natural gas and hydro-power was on the decreasing trend. In 2007, the indigenous energy of petroleum, natural gas and hydro-power only amounted to 17.8, 412.2, and 420.4×10^3 KLOE, respectively, as respectively compared with 182.4, 1304.3, and 610.0×10^3 KLOE in 1990. By contrast, renewable energy, which mainly includes geothermal, wind power, solar photovoltaic and solar thermal, was on the significant increase in Taiwan from 22.3×10^3 KLOE in 1990 to 148.1×10^3 KLOE in 2007.
(4) With the economic growth and the raise of living standards raised, the domestic energy consumption in Taiwan linearly increased from 50.7 million KLOE in 1990 to 121.0 million KLOE in 2007 (Table 1), which is equivalent to an annual average growth rate of 5.2%. The annual average growth in domestic energy consumption during the years of 2001–2007 (i.e., 98.8 and 121.0 million KLOE in 2002 and 2007, respectively), however, was only 3.4%, showing that the governmental

Table 1
Main energy indictors of Taiwan[a].

Year	Energy supply[b] (10^3 KLOE)	Energy requirement[c] (10^3 KLOE)	Final consumption[d] (10^3 KLOE)	Domestic consumption[e] (10^3 KLOE)	Dependence[f] (%)
1990	58,586	52,878	45,710	50,699	95.83
1991	59,294	58,544	48,711	53,589	97.03
1992	64,386	61,450	51,859	56,932	97.19
1993	69,110	65,082	53,645	59,249	97.78
1994	72,827	67,058	57,536	64,049	97.68
1995	79,503	71,610	60,050	66,931	97.90
1996	83,723	75,340	62,998	70,266	98.13
1997	88,524	79,722	66,448	74,216	98.26
1998	92,449	84,455	73,103	81,450	98.23
1999	99,319	87,851	77,037	85,499	98.48
2000	105,495	92,498	83,869	92,819	98.72
2001	108,791	99,026	89,063	98,759	98.67
2002	113,992	105,102	92,461	101,872	98.90
2003	121,974	109,099	97,211	106,840	98.98
2004	135,053	113,850	100,612	110,535	99.10
2005	136,183	115,415	102,352	112,678	99.22
2006	139,510	118,374	104,755	115,396	99.28
2007	147,241	126,537	110,542	121,029	99.32

[a] Source: [2]; unit: KLOE (kiloliters of oil equivalent).
[b] Energy supply = Production + Imports + Exports + Bunkers ± Stock change ± Product transfer + Loss + Statistical difference.
[c] Energy requirement = Production + Imports − Exports − Bunkers ± Stock change.
[d] Final consumption (by sector) = Industrial + Transportation + Agricultural + Service + Residential.
[e] Domestic consumption = Final consumption + Energy sector own use.
[f] The dependence is defined as the ratio of imported energy to total energy supply (i.e., indigenous energy + imported energy).

promotion for energy conservation and renewable energy has secured significant benefits in recent years. In 2007, domestic consumption by energy use consumed 115.8 million KLOE, which was an increase of 4.4% over the previous year. As classified by energy form, the consumption amounts (and their corresponding percent increases over 2006) of coal & coal products, petroleum products, natural gas, LNG, electricity, and solar thermal are 9319 (7.7%), 45,079.4 (5.8%), 1339.5 (1.1%), 1348.3 (7.9%), 58,646.3 (2.8%), and 105.5×10^3 (3.0%) KLOE, respectively.

2.2. Current status of biomass energy production

According to the data by the Bureau of Energy under the Ministry of Economics Affairs [5], bioenergy was used in two different ways: one was used as transportation fuel in city transport bus and refuse truck, and another was to utilize them, including municipal solid waste (MSW) and agricultural/industrial wastes, as electricity generation from cogeneration system or combined heat and power (CHP). The former was only 5500 kL of oil equivalent in terms of design capacity in 2005. With respect to the later, 84.1% (approximately 46.6×10^7 W in terms of installed capacity), 11.7% (approximately 6.5×10^7 W in terms of installed capacity) and 4.2% (2.3×10^7 W in terms of installed capacity) of biomass energy utilization in 2005 were from municipal solid waste incinerators, sanitary landfill gas (LFG) and other utilization utilities of agricultural/industrial wastes (including bagasse, rice husk, waste paper, black liquor, waste tire and waste plastics), respectively.

In order to achieve the goals of 74×10^7 and 103×10^7 W of biomass energy in terms of installed electricity capacity in 2010 and 2020, respectively, it is expected that using combustible industrial wastes (e.g., spent solvent, waste plastic/rubber/textile, waste wood, and biosludge), agricultural dried by-products (e.g., rice straw, bagasse, corn cob, plant stalk, and coconut shell), and dry matters of energy crops will be the main alternatives co-fired to the incinerator and industrial boiler because the current waste-to-energy from MSW incinerators will decrease significantly in the near future due to the new MSW recycling policy [11].

3. Estimation of CO_2 emissions relating to the energy use

Carbon dioxide emissions from the combustion of fossil fuels such as coal, petroleum and natural gas are the most important source of anthropogenic emissions of greenhouse gases all over the industrialized countries. With respect to the national inventories of CO_2 emissions from anthropogenic sources in Taiwan, the Taiwanese Environmental Protection Administration (EPA) first issued the report regarding the United Nations' Framework Convention on Climate Change (UNFCCC) National Communication of Taiwan in 2002 [12]. It was summarized that total CO_2 emissions without land-use change and forestry (LUCF) in the Taiwan area was about 240 million metric tons in 2000, in which the energy sector (combustion of fossil fuels) was the largest source (over 96%), and the next important source of CO_2 emissions was from the sector of industrial processes.

It is easily available to estimate carbon dioxide emissions from fossil fuel consumption using the Reference Approach of the Intergovernmental Panel on Climate Change (IPCC) method [13]. This reference method first estimates "apparent consumption" of fossil fuels using national energy statistics according to the International Energy Agency (IEA) reporting form. Thus, apparent consumptions of primary fuels (including coals, crude oil, natural gas, and natural gas liquids) can be obtained by subtracting the consumption for non-energy use from the domestic consumption. The apparent consumptions of primary fuels for 1992–2007 were displayed in Table 2. It also showed that the ratio of fossil energy consumption to domestic energy consumption was on the increasing trend from 1992 to 2000. However, the ratio approached a plateau (about 86%) since 2001, indicating that the fossil fuels consumption for non-energy uses, which consisted of oil-based petrochemical feedstocks, asphalt, lubricating oils and grease, naphtha specialties, petroleum coke and other products, was significant in recent years.

Table 2
Fossil energy consumption from energy use (consumption) in Taiwan[a].

Year	Solid fuel (Coal)	Liquid fuel (Petroleum)	Gas fuel		Sum	Ratio[b] (%)
			Natural gas	Natural gas liquids		
1992	13,275.5	29,294.4	1,100.7	1,494.2	45,164.8	79.3
1993	14,379.9	30,530.9	1,135.0	1,376.9	47,422.7	80.3
1994	15,364.5	33,076.4	1,236.2	2,075.9	51,753.0	80.8
1995	15,772.2	35,052.2	1,266.8	2,243.3	54,334.5	81.2
1996	17,989.1	35,283.4	1,268.9	2,382.8	56,924.2	81.0
1997	20,284.3	36,393.6	1,259.6	2,980.9	60,918.4	82.1
1998	23,389.2	37,571.4	1,256.6	4,533.9	66,751.1	82.0
1999	24,465.0	39,718.7	1,258.8	4,828.2	70,270.7	82.2
2000	29,111.9	41,527.9	1,433.7	5,514.9	77,588.4	83.6
2001	32,049.9	45,280.7	1,328.8	6,260.5	84,919.9	86.0
2002	33,882.7	44,032.1	1,294.1	7,491.5	86,700.4	85.1
2003	36,117.6	45,506.1	1,305.0	8,020.7	90,949.4	85.1
2004	36,695.1	47,057.8	1,323.2	9,875.5	94,951.6	85.9
2005	37,781.2	46,999.3	1,368.1	10,563.4	96,712.0	85.8
2006	39,510.9	47,645.8	1,329.6	10,941.9	99,428.2	86.2
2007	41,113.2	49,449.2	1,344.2	12,143.0	104,049.6	86.0

[a] Source: [2]; unit: 10^3 KLOE (kiloliters of oil equivalent).
[b] The ratio of fossil energy consumption to domestic energy consumption (seen in Table 1).

Next, apparent consumptions of primary fuels needed to be converted to a common energy unit (e.g., TJ) using a conversion factor (i.e., 1 L of oil equivalent = 9000 kcal = 37,674 J). Once apparent consumption represented by energy unit has been estimated, the coming calculations was carried out using effective fuel-specific CO_2 emission factor (kg/TJ) [13], where the fraction oxidization factor was assumed to be 100% for primary fuels based on the IPCC guideline. In this work, the default carbon contents of coal, petroleum (as crude oil), natural gas and natural gas liquid are 26.0, 20.0, 15.3 and 17.5 kg/GJ, respectively [13]. As a result, effective CO_2 emission factors of coal, petroleum (as crude oil), natural gas and natural gas liquid are 95,333, 73,300, 56,100 and 73,300 kg/TJ, respectively. Table 3 summarized the results in estimating total CO_2 emissions from the combustion of fossil fuels in Taiwan by the years of 1992–2007. It showed that the CO_2 emissions from the combustion of fuels increased from 134.5 million metric tons in 1992 to 258.1 million metric tons in 2001, averaging an annual increase of 7.24%. By contrast, the CO_2 emissions from the combustion of fuels slightly increased from the data in 2001 to 316.4 million metric tons in 2007, an average of only 3.39% increase each year, showing that the governmental promotion of greenhouse gases emissions mitigation has obtained significant benefits in recent years [14]. Upon analysis, the CO_2 emission per capita in the Taiwan area is 6.47 metric tons in 1992, 7.56 metric tons in 1995, 9.18 metric tons in 1998, 11.52 metric tons in 2001, 12.71 metric tons in 2004, and 13.78 metric tons in 2007. The average annual rate of increase represents 5.04% during the period of 1992–2007.

4. National energy goal in bioethanol and biodiesel supply

In Taiwan, ethanol (95%) has been produced commercially from sugar manufacturing by-product (i.e., molasses) under batch yeast fermentation for more than 50 years in Taiwan Sugar Corporation (TSC) [7], which is a state-owned enterprise. It was recorded that TSC had an annual production capacity of about 25,000 kL in the years of 1980–2000 based on the feedstock (i.e., molasses) using around 120,000 metric tons at three sugar mills. However, TSC, the only sugar manufacturer in Taiwan, has gradually reformulated its production strategy since the early 1980s in response to the international sugar market and business diversification. Since Taiwan's entry into World Trade Organization (WTO) on Jan. 1, 2002, the alcohol production from molasses has been halted

Table 3
The estimation of CO_2 emissions from energy use (consumption) in Taiwan from since 1992[a].

Year	Solid fuel (coal)[b]	Liquid fuel (petroleum)[b]	Gas fuel[b]		Sum (Gg CO_2 Eq.)	CO_2/population (t CO_2/capita)
			Natural gas	Natural gas liquids		
1992	47,680.0	80,896.6	2,326.4	3,614.0	134,517.0	6.47
1993	51,646.5	84,311.2	2,398.8	3,330.3	141,686.8	6.75
1994	55,182.8	91,340.6	2,612.7	5,020.9	154,157.0	7.28
1995	56,647.0	96,796.8	2,677.4	5,425.8	161,547.0	7.56
1996	64,609.2	97,435.3	2,681.8	5,763.2	170,489.5	7.92
1997	72,852.6	100,501.1	2,662.2	7,209.8	183,225.7	8.43
1998	84,004.1	103,753.6	2,655.8	10,966.0	201,379.5	9.18
1999	87,867.9	109,683.4	2,660.5	11,677.8	211,889.6	9.59
2000	104,557.6	114,679.5	3,030.1	13,338.7	235,605.9	10.58
2001	115,109.6	125,042.8	2,808.4	15,142.1	258,102.9	11.52
2002	121,692.3	121,594.8	2,735.1	18,119.5	264,141.7	11.73
2003	129,719.1	125,665.3	2,758.1	19,399.4	277,541.9	12.28
2004	131,793.2	129,950.3	2,796.6	23,885.6	288,425.7	12.71
2005	135,694.0	129,788.8	2,891.5	25,549.4	293,923.7	12.91
2006	141,906.4	131,574.1	2,810.1	26,464.9	302,755.5	13.23
2007	147,661.2	136,554.2	2,841.0	29,369.9	316,426.3	13.78

[a] Unit: thousand metric tons (Gg) of CO_2.
[b] Emissions are calculated using reference approach. In this work, the default carbon contents of coal, petroleum (as crude oil), natural gas and natural gas liquid are 26.0, 20.0, 15.3 and 17.5 kg/GJ, respectively [13].

because Taiwan offered its market for imported alcohol. By contrast, the first demonstration plant in the production of biodiesel fuels from waste edible oils on an industrial scale of 3000 m^3 per year has been commercially operated in Oct. 2004 under the policy encouragement from and financial incentives by the central government of Taiwan [6].

In order to formulate Taiwan's future energy and industrial development strategy in response to the Kyoto Protocol, the National Energy Conference was held in the summer of 2005 by the central responsible agency (i.e., Ministry of Economic Affairs, MOEA). One of the concrete action plans based on the conclusions of the National Energy Conference is to develop and promote the green (renewable) energy of achieving goals of about 500×10^7 W in terms of installed electricity capacity, or approximately 4% of total energy demand in 2010, and of about 750×10^7 W in terms of installed electricity capacity, or approximately 5% of total energy demand in 2020. With respect to the promotion of biomass energy, there are two development goals in the concrete action plans, which are summarized as follows:

(1) Biofuels:

Biofuels	2010	2015	2020
Bioethanol	100–300 $\times 10^7$ L	100–300 $\times 10^7$ L	100–300 $\times 10^7$ L
Biodiesel	10×10^7 L	–	15×10^7 L

(2) Electricity generation from waste-to-energy:
Year of 2010: 74×10^7 W.
Year of 2015: 85×10^7 W.
Year of 2020: 103×10^7 W (approximately 1.4% of total electricity in terms of installed capacity).

5. Government policies for encouraging biofuels production and consumption

In the past five years (2001–2006), Taiwan made great progress in creating mechanisms to address its energy policies: Petroleum Administration Act (PAA) revised in Oct. 2001, the Statute for Renewable Energy Development (Draft) passed by the Executive Yuan in Aug. 2002 and now pending in the Legislative Yuan, and the Bureau of Energy (BOE) upgraded from the Energy Commission under the Ministry of Economics Affairs (MOEA) in Jan. 2004. With respect to the economic/financial policies, the promotion regulations related to the biomass energy are mainly based on the Statute for Upgrading Industries (SUI) in Taiwan, which was revised recently in Jan. 2008. According to the newly revised SUI, important features concerning the aspects of utilizing biomass energy utilities (including biofuels production equipment) have been described in the previous paper [6]. Under the authorization of Article 6 of SUI, the regulation, known as "*Regulation of Tax Deduction for Investment in the Procurement of Equipments and/or Technologies by Energy conservation, or emerging/Clean Energy Organizations*", has been promulgated by the Ministry of Finance (MOF) and was recently revised in Mar. 2006. Regarding the agricultural policies for promoting biomass energy, the Agricultural Development Act was enacted to ensure the agricultural sustainability and was mainly revised in Feb. 2003, the central competent authority (i.e., Council of Agriculture, COA) has taken a set of promotion measures to encourage the plantation of local energy crops for the production of biodiesel and bioethanol for the purpose of achieving a balance among economic development, energy supply, agricultural productivity, and environmental protection. Table 4 listed the development goals of biodiesel and bioethanol in the years of 2006–2011 according to the joint-action of MOEA and COA.

5.1. Energy policy for promoting biofuels

In response to the impacts of energy crisis and changes in the 1970s, Petroleum Administration Act was passed in Oct. 2001. The main goals of this act are to promote the sound development of the oil industry, and to safeguard the production and sales of oil in the commercial market. Under the authorization of the Article 38 of PAA, an enterprise engaging in the production of renewable energies of alcoholic gasoline, biodiesel, and oil from recycled waste must lodge an application with the central competent authority (i.e., MOEA) prior to the approval for setting up the enterprise. The Bureau of Energy of MOEA promulgated the regulations (i.e., "*Measures for the Administration of Enterprise Engaging in the Production of Renewable Energies of Alcoholic Gasoline, Biodiesel, and Oil from Recycled Waste*") in Dec. 2001. Recently, this regulation was further amended in Jul. 2004. According to the Provision 2 of the regulation, the alcoholic gasoline refers to gasoline that is mixed with alcohols as fuel, and biodiesel, which is derived from the process of transesterification conversion by vegetable oil/animal fat or used edible oil, refers to methyl esters that is directly used or mixed with diesel as fuels.

In order to further promote and encourage the bioethanol and biodiesel development, the Executive Yuan has submitted the revision of PPA to the congress (Legislative Yuan) for reviewing and legislating in Mar. 2007. The Executive Yuan intended to revise the Article 38 of PAA as follows: an enterprise engaging in the production, import, blending, and marketing of alcoholic gasoline, biodiesel, and regenerative oils from recycled waste must lodge an application with the central competent authority (i.e., MOEA) prior to the approval for managing the enterprise. In addition to the revision, the central competent authority (i.e., MOEA) is requested

Table 4
Development goals of biodiesel and bioethanol in Taiwan.

Green biofuel	Time frame/quantitative goal/promotion measures			
Biodiesel	2006	2007	2008–2009	2010–2011
Amount (kL)	650	6,500	45,000	100,000
Promotion model	Green bus	Green county	All B1	All B2
Supplier	Appointed local market		(Open all market)	
Plantation area (ha)[a]	2,000	8,000	20,000	80,000
Bioethanol	2006	2007–2008	2009	2010–2011
Amount (kL)	–	770	12,000	100,000
Promotion model	–	Green official car	E3 (Urban area)	All E3
Supplier	Prior to local market, import overseas if insufficient			(Open all market)
Plantation area (ha)[a]	30 + 5	30 + 100	3000	20,000

[a] Development goal in plantation area may be adjusted to fulfill the needs for food.

to set up the regulation of promotion measures, which include the ratios of blending bioethanol into gasoline and blending biodiesel into diesel, and its implementation timetables, scopes and ways, when the local petroleum refineries and importers domestically sell gasoline and diesel.

According to the action plan of MOEA for promoting biofuels, there are four stages in progress (Table 4):

1. First stage (the years of 2006–2007): green bus

   Prior to the action plan, some trash or municipal solid waste trucks in the metropolitan cities (e.g., Taipei city, Kaohsiung city, Taichung city, and Tainan city) of Taiwan have used mixed diesel fuel B20 (i.e., 20% biodiesel and 80% petroleum diesel) in diesel engines under the funding assistance by the central competent authority responsible for improving air quality (i.e., Environmental Protection Administration). Further, during the years of 2006–2007 the Bureau of Energy and the Council of Agriculture (COA) are making joint efforts to execute the plan (called "energy crops-green bus") to actively promote the use of biodiesel domestically produced by local energy crops. Under the funding assistance, the public transportation system (i.e., government-owned bus) was encouraged to use the B1–B5 diesel for the purpose of encouraging the plantation of local energy crops by COA (described later), assisting the build-up of domestic energy crops market, and reducing the emissions of greenhouse gases and air pollutants.
2. Second stage (the years of 2007–2008): green county/green official car

   This stage is being in progress for the purpose of constructing local production-marketing-supply system. The green county promotion program is to utilize the set-aside (fallow) rice field for planting potential energy crops, to assist the energy producer in locally investing oil-pressing/extracting and biodiesel production facilities, and to demonstrate the marketing of biodiesel in the local gas stations. In brief, the biodiesel promotion program is intent in establishing a demonstrated and constructive mechanism for the comprehensive B1–B3 promotion in the near future. On the other hand, the bioethanol promotion was only limited to official cars for the purpose of showing the government's determination because there are no local bioethanol production plants on the current market.

According to the Article 38 of PPA, the quality and composition of biodiesel products manufactured from renewable energy enterprise must comply with the national standards prior to marketing. Table 5 showed the national standards (CNS 15072), dated on Mar. 2007, for the quality and composition of biodiesel fuels by the Bureau of Standards, Metrology & Inspection (BSMI) under MOEA in Taiwan. It is also noted that the national specification standards for biodiesel fuel rested on the basis of other built industry specifications like the American Society of Testing and Materials (ASTM) standard (D 6751) and German standard (DIN V 51606) [15,16]. On the other hand, the composition standard of CNS 15072 is relatively strict because the cetane index in biodiesel from spent edible oil is always less than 50. It implies that the usage of biodiesel must be mixed with traditional diesel fuel, not absolutely used in diesel engines. Regarding the national standards for bioethanol fuel, the CNS 15109, which is entitled as "Denatured fuel ethanol for blending with gasoline for use as automotive spark-ignition engine fuel", was recently announced on Jun. 23, 2007 by the Bureau of Standards, Metrology & Inspection under MOEA in Taiwan. The specifications for the quality and composition of denatured fuel ethanol was listed in Table 6, showing that industrial ethanol (generally contains 95% ethanol and 5% water) produced from the fermentation process must be further purified into denatured fuel ethanol using azeotropic distillation. It should be noted that the purpose of blending a small percentage of water-free ethanol into gasoline is to oxygenate the automobile fuel for cleaner combustion and less air pollutants (i.e., carbon monoxide and hydrocarbon) emissions [17]. In addition, the blends are also intended to eliminate the

Table 5
National standards for biodiesel (fatty acid methyl esters) as diesel engine fuel in Taiwan[a].

Standard/specification (test value)	Range		Unit
	Minimum	Maximum	
Ester content	96.5	–	% (m/m)
Density	860	900	kg/m^3
Kinematic viscosity	3.50	5.0	mm^2/s
Flash point	120	–	°C
Sulfur content	–	10.0	mg/kg
Carbon residue on 10% distillation residue	–	0.30	% (m/m)
Cetane No.	51.0	–	
Sulfate ash	–	0.02	% (m/m)
Water content	–	500	mg/kg
Total pollutes	–	24	mg/kg
Copper strip corrosion (3 h, 50 °C)	No. 1	Grading	
Oxidation stability (110 °C)	6.0	–	h
Acid No.	–	0.50	mg KOH/g
Iodine No.	–	120	g I_2/100 g
Linolenic acid methyl esters	–	12.0	% (m/m)
Poly-unsaturated (≧4) fatty acid methyl esters	–	1	% (m/m)
Methanol content	–	0.20	% (m/m)
Monoacylglycerol content	–	0.80	% (m/m)
Diacylglycerol content	–	0.20	% (m/m)
Triacylglycerol content	–	0.20	% (m/m)
Free glycerol content	–	0.02	% (m/m)
Total glycerol content	–	0.25	% (m/m)
Alkali metals (Na + K)	–	5.0	mg/kg
Alkaline metals (Ca + Mg)	–	5.0	mg/kg
Phosphorus content	–	10.0	mg/kg
Cold filter plugging point	–	−5 (C grade)	°C

[a] CNS 15072 dated on 2 Mar. 2007.

Table 6
National standards of denatured fuel ethanol for blending with gasoline for use as automotive spark-ignition engine fuel in Taiwan[a].

Standard/specification (test value)	Range		Unit
	Maximum	Minimum	
Appearance/color	No suspensions and settlings (clear and bright)		
Density	–	0.7915	g/mL
Ethanol content	99.3	–	% (v/v)
Methanol content	–	0.5	% (v/v)
Water content	–	0.5	% (v/v)
Copper content	–	0.07	ppm (m/m)
Sulfur content	–	30.0	ppm (m/m)
Total acids (denoted as acetic acid)	–	30	mg/L
pH	6.5	9.0	h
Conductivity	–	500	μS/m
Added denaturant content	2	5	% (v/v)

[a] CNS 15109 dated on 23 Jun. 2007 is applied to water-free denatured fuel ethanol, which can be blended with automobile gasoline in the ratio of 1–10% (i.e., E1–E10 gasoline).

use of the most common chemical (i.e., methyl tertiary butyl ether, MTBE) due to its highly toxic properties and the possibility of contaminating groundwater.

3. Third stage (the years of 2008–2009): all B1/E3 (urban area)

   According the Amendments of PPA being reviewed by the congress (Legislative Yuan), the Taiwan' government will execute a compulsory promulgation, which aimed at supplying B1 diesel at all gas stations from the beginning of Jul. 1, 2008. Under the economic/financial encouragement from MOEA, there are at least seven biodiesel production plants being established in the industrial parks. Compared with the modest land resource and small domestic market in Taiwan, a relatively large amount of energy crops used as feed stuffs will be imported from the nearby countries (e.g., Philippines, Vietnam, and Thailand), and the biodiesel products will be consumed in the domestic market and/or exported to the Eastern Asian countries (i.e., Japan and Korea). By contrast, the bioethanol promotion will be not mandatory at this stage mainly due to an obstacle to production technology and a relatively high cost as compared with the oxygenated gasoline fuel in the current status. The gas stations in Taipei city, however, will gradually supply E3 gasoline, which is cheaper than the conventional gasoline, under the funding assistance by MOEA. Afterwards, the E3 gasoline promotion program will expand to other urban cities such as Kaohsiung city.

4. Fourth stage (the years of 2010–2011): all B2/all E3

   Following the third stage, the Taiwan's government intends to act as a pioneer of biofuel development in Asia. At this stage, the gas stations all over the Taiwan area must supply B2 diesel and E3 gasoline in the market. As described above, the biofuels forcibly marketed by the domestic manufacturers/suppliers is established on the basis of the PPA Amendments.

5.2. Agricultural policy for promoting energy crops

Concern about global warming in recent years has stimulated the potential in sustainable cultivation concepts of domestic fuel production from energy crops. As a result, the farmers have the chance to participate in the plantation of energy crops with high biomass yield potential and thus play a vital role in energy producers. Traditionally, the main function of agricultural land is to provide food and feed to sustain the human life and living welfare in essence. From the viewpoint of renewable resources, the land soil can be considered as an effective organic converter for transforming the solar energy into environmentally green and clean bioenergy by photosynthesis.

In order to maintain a harmonious balance among the agricultural production, energy security and environmental protection, the central competent authority (i.e., Council of Agriculture, COA) has developed a sustainable agricultural policy and taken a set of promotion measures to encourage the plantation of local energy crops for the production of biodiesel (from soybean, sunflower, and rapeseed) and bioethanol (from sweet potato and sugarcane) in the years of 2006–2011. Prior to the promotion program on the way, its SWOT (Strength-Weakness-Opportunities-Threats) analysis of trends toward energy crops development in Taiwan includes

- Strength
  - Potential for breed, cultivation, and research & development.
  - Complete agricultural extension system.
  - Mature bioenergy production technology with biodiesel and bioethanol factories.
- Weakness
  - High production cost.
  - Small area of farmland and lack of large automatic cultivation.
  - Need to breed and select local crops and varieties.
- Opportunities
  - Supported by the government's energy and agricultural policies, and international trend to develop sustainable agriculture.
  - Apply to World Trade Organization green box policy.
  - Many areas of follow field can be released and used as energy supplier.
- Threats
  - No entire system from production to supporting.
  - The countries which are similar to Taiwan in climate will be our competitors in the open market.
  - No enough lands to fill the needs for food supply when the crops are used as an energy source.

Currently, many energy crops have been evaluated about their potentials to be cultivated in Taiwan, including the biomass yield, energy content (by sugar, starch, or oil), irrigation availability, soil adaptability, fertilizer usage, and growing period. Table 7 summarizes the characteristics and transfer rate of energy crops being promoted in Taiwan. In this energy crops promotion program, it is expected to progressively make about 40% of the fallow farmland (250,000 ha in the year of 2006) into green energy production fields shown in Table 4. Notably, the government offers NT$ 45,000 ha^{-1} (about US$ 1450 ha^{-1}) for environment investment, and additionally provides NT$ 15,000 ha^{-1} (about US$ 490 ha^{-1})

Table 7
Characteristics and transfer rate of energy crops being promoted in Taiwan.

Energy crop		Characteristics		Transfer rate		
Content	Variety	Energy content (wt%)	Growth period (day)	Transfer amount (Liter/ton)	Yield of crop (Ton/ha)	Yield of bioenergy (Liter/ha)
Sugar	Sugar cane	15–20 (Sugar)	~420	80	70	5,600
Starch	Sweet potato[a]	12–23 (Starch)	150	125	35–40	4,375–5,000
Oil	Soybean	20–25 (Oil/seed)	100	150	2.0–2.5	300–375
	Sunflower[b]	50–60 (Oil/seed)	100	350	1.3	455

[a] *Ipomoea batatas*, which is very suitable in Taiwan.
[b] *Helianthus annuus*, which is adapted to poor and salty lands.

for material and production costs if the crop gives a base yield. On the other hand, COA has aggressively taken actions on "*Ping Tung Agricultural Biotechnology Park*" with the multiple goals of ensuring permanent management of the agriculture by means of agricultural biotechnology under the authorization of the law (called "Act of Establishment and Administration of Agriculture Technology Parks") passed by the Legislation Yuan on Apr. 7, 2004. According to the standard established by the Park, two government-owned enterprises and one private enterprise are planning to invest in the fermentation production of bioethanol and the gasification production of alcoholic fuels, respectively, using local energy crops (including napier grass) in southern Taiwan. Also, the Park will provide administrative and economic incentives including subsides, tax deductions, low interest loans, accelerated depreciation of equipment, and special financing in order to encourage enterprises to set up in the Park.

6. Environmental considerations for utilizing napier grass as biomass energy

Many species of grasses have been considered as renewable sources because they are the most abundant flowering plants in the tropical and sub-tropical regions. Napier grass (*P. purpureum*), which is also known as elephant grass, is the most famous C_4 perennial grasses as a forage crop and non-forage energy crop due to its advantages: fast growth, disease resistance, adaptability, minimal management, and easy propagation [9]. At present it is an important fodder crop in Taiwan, where it was used almost exclusively for feeding dairy cattle in cut-and-carry systems. It should be noted that this grass can produce larger yields of dry matter in excess of 40 Mg/ha/year than most other plants [18]. It indicated that napier grass used as an energy crop is increasingly important partly due to its easy growth on fallowed land in Taiwan. A total energy output of 6.4×10^4 TJ/year can be gained based on the heating value of 16 GJ/Mg and napier grass field of 100,000 ha in Taiwan.

Although CO_2 emissions from the combustion of dry napier grass cannot be included into the national CO_2 inventories, other air pollutants and greenhouse gases (i.e., methane and nitrous oxide) emissions should be considered in the energy sector [19]. The methane (CH_4) emissions are derived from the incomplete combustion of hydrocarbons in it, but its production dependent on the temperature in the boiler/stove is generally in small quantities. However, it should be noted that CH_4 emissions from the agricultural biomass could be a significant contribution to the total CH_4 emissions in the energy sector. As with nitrogen oxides (NOx), nitrous oxide (N_2O) is produced directly from its combustion in the stationary combustors, because the chemically bound nitrogen present in the biomass fuels is oxidized to NOx (NO/NO_2). As examined by the authors, nitrogen concentrations (about 2% by weight) are relatively high in the biomass fuel, compared to those of most energy crops used as biomass fuels [20]. It should be noted that fuel-bound nitrogen will contribute to nitrogen oxides emission from biomass combustion facilities where they could have a need for installing NOx control systems. Just like common biomass fuels [20], the sulfur content of dry napier grass is very low (below 0.2 wt%, measured by the authors) compared with that of coal. It should be therefore expected that sulfur oxides (SOx) would not be emitted in a large extent. While the emissions of acid gases from biomass-fueled systems arouses concern, probably the most controversial pollutants from combustor or boiler emissions are the categories of chlorinated organics (i.e., dioxins/furans, or referred to as PCDDs/PCDFs), which may be formed as a result of incomplete combustion of chlorine-containing biomass.

7. Conclusions and recommendations

Since the Kyoto Protocol commissioned in 1997, the energy consumption concerning environmental issues and energy supply diversification have been the focus of environmental protection, agricultural policy and economic development in order to pursue sustainable development and create renewable energy in Taiwan. Because of the limited petroleum reserves and increased environmental concerns, biomass fuels from agricultural resources have become increasingly important in the past decade. Under the encouragement of energy and agricultural policies, the biofuels and electricity from local energy crops/grasses has been relatively attractive in this sub-tropical/tropical country. Their industrial and environmental benefits are to upgrade industrial investment in the bioenergy plants, reactivate the fallow land (about 100,000 ha), to increase the income of the farmer as energy producers, to induce the development of leisure and sightseeing industries, to create jobs from the domestic biofuels production, and to mitigate the carbon dioxide emissions. However, the emission of non-CO_2 greenhouse gases (i.e., CH_4 and N_2O) should be included in the calculation of net greenhouse mitigation using energy grasses (e.g., napier grass) or other agricultural residues as biomass energy. To greatly promote the use of biofuels as one of the clean alternatives to petroleum-based fuels in Taiwan, the following measures are recommended and enhanced:

- Increase the subsidy for use of biofuels from local energy crops in diesel engines under the support of special funds such as Air Pollution Control Fee and Petroleum Fund, or other financial tools (e.g., carbon tax). Currently, the biofuels are too expensive to compete with petroleum-based fuels in the commercial market.
- Develop emerging biotechnology for bioethanol production from local biomass resources (including sugarcane bagasse, rice straw, rice husk, coconut shell, bamboo, energy grass, and woody residues), especially in innovative enzyme, gene splicing, and continuous fermentation.
- Grant industrial enterprises, preferentially one state-owned enterprise (i.e., Taiwan Sugar Co., Taiwan Fertilizer Co., or joint-venture by Chinese Petroleum Co.), to build a modern

demonstration plant of bioethanol production in Southern Taiwan for the purpose of utilizing local energy crops and reducing transportation and production costs.

- Analyze a feasibility of utilizing local energy crops in the production of alcohol-based fuels and biodiesel to obtain the ratio of output energy to input energy or net environmental benefits on the basis of environmental tool called life cycle assessment (LCA). The evaluation phases in the LCA system should include plantation, harvesting, packing, transportation, storage, pretreatment, conversion, and marketing.
- Promote other potential energy grasses. For example, napier grass (elephant grass or *P. purpureum*) has emerged as a leading candidate for biomass utilization among energy grasses due to high energy and dry matter yield, fast growing, ease of culture and great adaptability. Its biomass yield can be attained in excess of 40 metric ton (dry matter)/ha/year.
- Develop decentralized small- and medium-sized combined heat and power plants in the rural community to generate electricity from the emerging energy grasses (e.g., napier grass) for local industries and will possibly create jobs in the agricultural counties.
- Co-fire the local energy grasses and agricultural residues from food/energy crops with municipal solid wastes in the existed MSW incineration facilities because these mass-burn incinerators will generate lots of marketable electricity through steam turbine-generator (cogeneration) system. This approach will be more significant to contribute the output of biomass energy because the amount growth of MSW is moderating mainly due to the promotion of resource recycling in the past decade.

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